About Altra Industrial Motion

Altra is a leading global designer and manufacturer of quality power transmission and motion control products utilized on a wide variety of industrial drivetrain applications. Altra clutches and brakes, couplings, gearing and PT component product lines are marketed under the industries most well known manufacturing brands. Each brand is committed to the guiding principles of operational excellence, continuous improvement and customer satisfaction. Highly-engineered Altra solutions are sold in over 70 countries and utilized in a variety of major industrial markets, including food processing, material handling, packaging machinery, mining, energy, automotive, primary metals, turf and garden and many others.

Altra's leading brands include Ameridrives, Bauer Gear Motor, Bibby Turboflex, Boston Gear, Delroyd Worm Gear, Formsprag Clutch, Guardian Couplings, Huco, Industrial Clutch, Inertia Dynamics, Kilian, Lamiflex Couplings, Marland Clutch, Matrix, Nuttall Gear, Stieber, Stromag, Svendborg Brakes, TB Wood's, Twiflex, Warner Electric, Warner Linear and Wichita Clutch.

Formsprag Clutch®
Altra Industrial Motion

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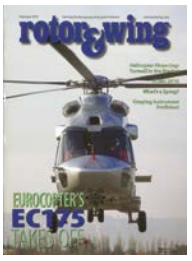
Autorotation is a Sprag Thing

As seen in
Rotor & Wing
February, 2010



Formsprag Clutch®
Altra Industrial Motion

Autorotation is a Sprag Thing

To the uninitiated, the small sprag clutch rotating along in the drive-train of a helicopter seems somewhat insignificant. Amidst the myriad of components that comprise a helicopter, it's a relative unknown.

But when the engine or drive-train fails on a rotary wing aircraft, the little clutch buried inside permits the autorotation that can keep the helicopter aloft and allow the pilot to guide the rotorcraft to a safe landing without having to do anything to disengage the rotor.

Mike Hines, a former Army flight medic and now a Quality Inspector at Formsprag Clutch in Warren, Michigan, knows a sprag clutch's critical importance from his experience in rotary wing aircraft over the jungles of Central America.

"We were flying an NOE (Nap of the Earth) mission in a Bell Huey, flying as close to the ground as possible, when we came across a big ravine," Hines said. The aircraft pitched nose down and Mike felt that they were going to have some problems when the aircraft descended quickly. "It felt like we were having a power failure, but the pilot was able to keep control, and I am thankful he did!"

Only afterward did Hines come to learn more details about the sprag clutch design that causes the sprags to engage and hold during drive, while overrunning during an autorotation. "Of course I didn't know what a sprag was, and had never heard of a sprag clutch. Now to be part of the inspection team at Formsprag, that's really a privilege. I believe every helicopter should have them. I also experienced a power failure in a helicopter that didn't have a Formsprag clutch. The autorotation didn't go well and we crashed into the trees."

Formsprag sprag retainer assemblies permit each sprag to have free and independent action. This independence allows each sprag to adapt to variations in annular space (eccentricities) so that when the clutch is engaged, the load is proportionately shared among all sprags, eliminating the possibility of clutch damage resulting from the entire load being absorbed by just a few sprags. This insures dependable performance without compromising size, weight, or cost.

Ubiquitous Yet Unseen

The story of autorotation is the story of how something so small – a sprag one way or overrunning clutch – can play such a big role in the helicopter industry. Fact is, of the dozen or so major helicopter manufacturers in the world, all but a handful are using Formsprag overrunning sprag clutches to provide autorotation in their rotorcraft… and the last major builder without them is currently including them in its newest program.

Although they're seldom larger than a few inches in diameter and a couple inches in length, Formsprag overrunning clutches perform some of the most critical functions within the aircraft. In addition to permitting drive during normal operations and autorotation during emergency situations, sprag clutches are integral to the transmission gearboxes of multi-engine helicopters to allow twinning of the engines for efficient power sharing and synchronization or disengagement of one engine. As purely mechanical devices they require no pilot or flight control input.

In commercial jets, the sprag retainer assemblies are used in the starter drive of the jet turbine engine to provide automatic disconnect from the gas turbine engine upon light-up. They're also in the starter drive of auxiliary power units (APUs) to automatically disconnect the starter after powering up.

Ask a helicopter pilot, Hines says, and he may not know anything

Tom Long "grew up" with Ted at Formsprag, beginning as a Mechanical Engineer in 1957 and later as Marketing Manager of the Industrial Power Transmission Division of Dana Corp., when it owned Formsprag. Long remembers when Formsprag first sold overrunning clutches to Bell Helicopter for the Hueys they supplied to the Army throughout the Vietnam War:

"That really put us on the map. Ted was there in the beginning – and he's still there! At 90 years old – he's really an international figure in the industry. The Germans, Italians, French, Japanese – they all know and respect Ted. Ted's designs are the best in the world. He deserves kudos for all he's done for Formsprag and the helicopter industry."

Italy's Giuseppe Gasparini, Engineering Manager-Transmissions, for AgustaWestland, also has a long history with Ted:

"Formsprag clutches have been used in AgustaWestland helicopters for at least 40 years. We use them on all our transmissions – about 10 main models – because we like their simplicity, ruggedness and quality of detail. I've known Ted for about 25 years and I've always appreciated his ingenuity, his open mind, his willingness to review and study the details of a design as if it was his first time."

In France, Gerard Paty, Research & Technology Program Manager, Turbomeca/SAFRAN Group, recalls his first "overnight" fax conversations with him:

"We were searching for a new clutch 20 years ago, so I would send a fax to Ted, and overnight while I was sleeping (because of the time difference between Michigan and France), he would send answers to our questions and we'd have them the next morning. He provided a lot of information and we were able to progress rapidly on our project which was very helpful because we had a very urgent need. Not only was he thinking about the clutch design, but also about the components of the entire system which helped us improve the quality of the whole system."

Frank Robinson, owner/founder of Robinson Helicopters, puts a Formsprag clutch on each of his rotorcraft. And at nearly 900 units per year, Robinson produces more helicopters than any other manufacturer in the world.

"We've been using Formsprag clutches since the early '80s, and we have always relied on Ted's technical judgment. He knows what he's doing. Ted shares some of my prejudices – he doesn't like data on a computer… he likes it on paper. I have a great deal of respect for Ted, as a person and an engineer. I hope to be able to work as long as he has. I turn 80 this year, so I guess I'm 10 years behind him!"

As a young man, Chuck Duello, formerly with Bell Helicopter and now Manager of the Transmission Group of Sikorsky Helicopters, learned about Ted's philosophy of work:

"I remember going out to lunch with Ted – here I was all of 30 years old and a newcomer to the helicopter transmission world – and I asked him what keeps him going. He just said, 'You quit work and you die.'

Personally, Ted is just a nice guy. Even though, when I was at Bell, we had some contentious issues to work through, he was always open-minded and receptive to all viewpoints. He was interested in innovation, trying new things, and in keeping the dialogue going. With Ted, you worked together on solving problems."

Walt Riley, Chief, Drive Systems Analysis of Bell Helicopter's Drive Systems Group, is among the Zlotek associates who are still learning from him:

"You can't have a conversation without learning something from him. I always look forward to talking with Ted. You can really tell he loves his work. You can't believe his energy, his drive and his knowledge. I understand he still goes to work every day, at 90, and I'll bet he goes home and chops wood every night. Whatever he does, he does it well."

And Curt Orkin, former Design Specialist at Kaman Helicopters, was among the Zlotek associates who jumped at the chance to pay tribute:

"Ted is the epitome of the engineer's engineer. Very practical, very analytical. He listens to your ideas, then formulates his own ideas, and he knows how to get through the 'weeds'. I worked with Ted for 20 years, and I never found a problem that was too big for him. Of course we had problems to work through, but Ted always had great insight as to how to lead the focus of the group going forward.
"He's always very calm, very steadfast – nothing seems to upset him. His longevity is truly impressive. His spirit has always remained young. Timeless."

Ted Zlotek provides insights and inspiration to members of the Formsprag aerospace team.

about a sprag clutch – even if he's survived an emergency autorotation descent. Ask an engineer involved in helicopter gearbox design, though, and he'll not only know about them, he'll very likely know about the world's foremost sprag designer, Formsprag's Ted Zlotek (see page 6).

How It Works

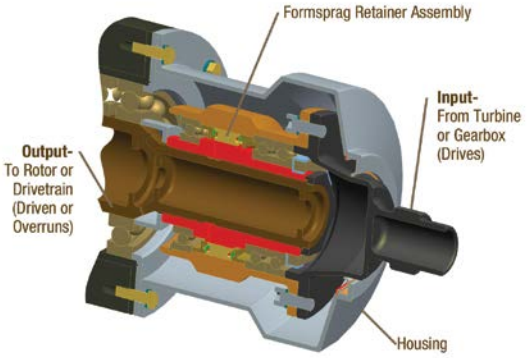
In simplest terms, a sprag overrunning one way clutch consists of a cylindrical inner race with a surrounding cylindrical outer race which forms an annular space between the two races. In helicopter applications, the annular space is generally filled with anywhere from one to four dozen sprags, held in a retainer by energizing springs. Each sprag is essentially a strut placed between the races in such a way that it transmits torque from one race to the other by a wedging action when either race is rotated in the driving direction. Rotation in the opposite direction disengages the sprags and the clutch freewheels or "overruns". You can think of it as a rolling bearing, but it only rolls freely and smoothly in one direction. In the other direction of rotation it is locked up like a solid shaft.

When the engine power is driving the drive-train of the helicopter (gearboxes, shafts, couplings, rotor, etc), the sprag clutch is engaged and rotating, or driving, along with the other transmission components. However, when the engine power is cut, the clutch overruns disengaging the rotor, and allowing it to rotate freely or "auto-rotate" due to its stored inertia and applied aerodynamic forces.

That's the simplified explanation of the basic design. But of course, every new helicopter application requires some development, new testing, redesign, engineering analysis, more testing…then there's heat treating, metal chromizing, changing of the center of gravity of the sprags, altering the tangent of the gripping angle, reduction of the PVs (pressure velocities) and Hertzian stresses…

The Art of Sprag Design

Sprag clutch applications vary widely depending on the aircraft. Rotational velocity may be extremely high (15,000 revolutions per minute or more). Functional temperature may dip to forty degrees below zero and reach as high as 120 degrees Centigrade (200 Fahrenheit). Lubrication under these conditions will depend greatly on available oil flow paths, aircraft or gearbox orientation, and the g-forces involved. Contact stress between mating components, inertia of rotating masses, angular accelerations, drive-train natural frequencies, and centripetal forces on clutch components all need to be understood, controlled and kept within design



Typical Formsprag sprag retainer assembly application for a helicopter drive-train.

guidelines during the most demanding drive and flight conditions. In the end, the clutch must simply function under all possible conditions. Sprag clutch design is an empirical science – knowledge only comes from experience. Yet, to succeed the design must start with a good idea or several good ideas coming from insight into what the application will demand, coupled with supporting calculations.

Walt Riley, Chief of Drive Systems Analysis for the Bell Helicopter Drive Systems Group in Ft. Worth, TX, has worked with Formsprag for over 20 years and describes the design process in somewhat open ended terms, especially for an engineer.

"The design of a sprag clutch is kind of esoteric," Riley says. "I used to call it 'intuitive design', but you can work out the physics. You just have to start with an intuitive feel that it's going to work." Riley says he learned that from Ted Zlotek.

Chuck Duello, manager of Sikorsky's Transmission Engineering Group in Ft. Worth, worked on clutch designs for Bell Helicopter with both Walt and Ted Zlotek for 25 years…and he speaks a similar language.

"Ted's knowledge comes from experience and just a willingness to try. The work he's in – well, heck there isn't a book. He wrote the book. It's intuition and judgment and gut feel that gets you started on a path, and of course it all has to be borne out through calculation, analysis and testing," Duello says.

"But it seems to work best when you start with a gut feel, followed with an empirical demonstration. You have to see it work first, and then you come back with analysis and theory and provide an explanation as to why. It's more like being a garage tinkerer than a rocket scientist, but it gets you there. And maybe it gets you there sooner or better than the rocket scientist can. I don't know. I really can't explain it. But it goes back to intuition and instinct, and experience.

From his perspective, Ted says you have to be able to visualize the design. Intuition? One of his best patented ideas came to him while driving down the road.

"You look at something, and it will tell you something," he says. "Depends on how you grew up. I was always inquisitive."

Zlotek's early education and career years were infused with hands-on industrial arts, but his Wayne State University degree was in Fine Arts. His master's degree was in the field of industrial design.

And of course, he's been designing sprags for the last 58 years. Since 1951. Obviously, the 90-year-old Zlotek is in a unique position to be able to visualize sprags.

A sprag-type overrunning clutch generally consists of an inner race, an outer race, and a set of sprags evenly spaced in the annular space between them.

Who Are Those Guys?

Nobody has counted, but the best guess is there are less than a dozen people in the world who design sprag clutches for helicopters.

"There's really nowhere to go to learn how to do this," said principal engineer Jim Shimon who has been with Formsprag since 1976. "It's really a matter of total experience with the application of the product, and exposure to the helicopter field."

Jim works side by side with Ted and a handful of other Formsprag engineers who design and develop sprag clutches for new helicopter applications and other demanding applications such as jet engines or high performance automobiles.

The Bell-Boeing V-22 Osprey

"There are a lot of other industrial and commercial applications, so we share our knowledge - a kind of cross-fertilization of ideas among different product lines," Jim says. "A lot of times, Ted starts with an idea and we'll run the numbers once he's sketched it out. Then we'll put together a test box for differential overrunning and torque testing.

"We'll test the clutch at maximum torque and velocity (PV), for oil flow and temperature rise. We'll cycle it maybe four to five million times and disassemble it every million cycles to make sure things are running smoothly and there's no fatigue. A lot goes on behind the scenes to get a clutch running in a customer's gearbox."

Twinning: The Bell-Boeing V-22 Osprey

Overrunning clutches are also designed into applications where power sharing between multiple gas turbine engines is required. Ted Zlotek was 68 years old when he and the Formsprag team were asked to design a clutch for a twinning application in the Bell Boeing V-22 Osprey. It was one of the toughest challenges ever presented in the design of sprag overrunning clutches for a helicopter application. Where the clutch

resides in the V-22 drive-train, the high-speed engine generates incredibly high surface velocities. In addition to the speed, high centrifugal forces and pressures, the clutch needs to transmit thousands of horse power, which means a lot of torque at those speeds.

On top of that is the problem of orientation. A helicopter drive-train clutch often spins on a horizontal shaft submerged in oil in a dammed up oil annulus. But because the V-22 nacelle can be tilted vertically, the clutch needs to operate in both a horizontal and vertical orientation, fully lubricated with no loss of function.

Beginning in 1987, the clutch design effort ended three years later with Chuck Duello, then at Bell, flying home from Michigan with clutches in his luggage, ready to start the ground testing of the Osprey.

"I spent some time and a few late hours up there in Warren, Michigan working with the hardware and the test stands," Duello says. "At the time, it was one of the toughest applications to-date in terms of PV (pressure velocity) – the contact pressure of the sprag and the sliding velocity of the sprag – due to the high torque requirement and engine speed.

"I know it was advancing the state-of-the-art at Bell and possibly the entire rotorcraft industry. We worked hand-in-hand with Ted and Jim and others, and ultimately we came up with a successful design that is flying now." – And instantly recognizable!

Patents, PCE & Formchrome®

In the years spanning the design and development of the V-22 clutch, Ted Zlotek registered two of the 19 patents credited to his long career, including a new process for surface hardening sprags called Formchrome.

The proprietary chromizing process, in which the surface of the hardened high carbon alloy steel sprags are infused with chromium to form a chromium-carbide alloy, provides extra-long life, maximum wear resistance and lower maintenance costs.

Ted's Formchrome patent and his patent of a new sprag design called PCE or Positive Continuous Engagement have been the two most influential changes to sprag design which allows Formsprag to assume a leadership role in the demanding applications of the aerospace industry, according to Jack Pederson, Business Manager, Aerospace & Defense.

Jack, in fact, joined the Formsprag engineering team in large part because of the many patents Ted had registered during his career.

"At a previous company, I worked in product development on overrunning clutches for the automotive market, and frequently came across the names Zlotek and Formsprag while searching the United States Patent Office database. The patent we eventually applied for referenced his work," Jack said. "Later, when I heard an engineering position opened up at Formsprag, the chance to work with Ted in the industrial and aerospace market was a very compelling reason to apply. It's not often you get to work with someone who has done a lot of the foundational work in a specific area of engineering."

PCE sprags, Jack explains, are a Ted Zlotek and Formsprag design innovation that provides built-in protection from damaging overloads, with the ability to overcome the effects of severe torsional and linear vibrations as well as high transient torque overloads.

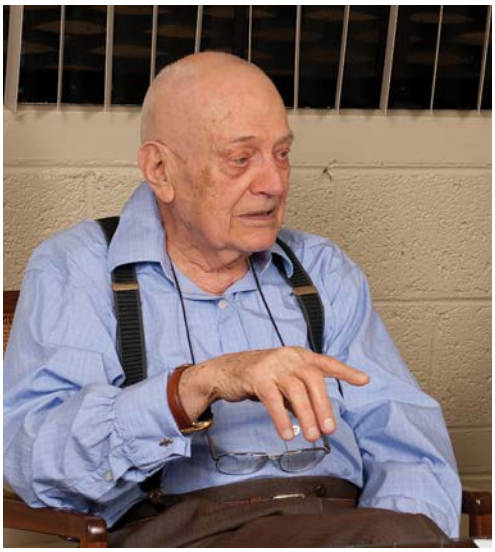
"PCE is what all the helicopters are using now," Ted says. "It's basically a sprag shape with some material here, and a nose here, to give it a cross section that prevents the sprags in a free-action retainer from rolling over and jamming up.

"You can move material around or add a notch to the profile that moves the center of gravity. So now we can play games to give this sprag centrifugal lift-off under certain conditions whereas this one will have centrifugal engagement."

Like the man says, it's all a matter of visualization. You look at something and it tells you something. To Ted Zlotek, a helicopter drive-train sprag can say an awful lot.

Formsprag manufactures a wide variety of sprag sizes and shapes to meet specific application requirements.

Ted Zlotek: Unassuming, Ingenious…Impressive



At 91 years of age, Ted Zlotek, Formsprag Director of Aerospace Products, and the designer of the original Formsprag sprag retainer clutch patented in 1959, still works five days a week.

OK, let's get the obvious out of the way. Ted Zlotek is 91 years old. He still works five days a week and puts in more hours than most men 1/3 his age.

That alone is impressive. And it is not lost on his co-workers. But Jim Shimon, the Formsprag Clutch engineer with whom he works most closely, simply says about his dedication, "I expect to see him here in the morning."

Ted's longevity, however, only skims the surface of impressiveness when you're talking about a man who is universally revered in the small yet global community of helicopter transmission engineers.

Ted Zlotek began his career at Formsprag Clutch in 1951, at the time helicopters were first proving their worth as transport and medivac rotorcraft during the Korean War. Helicopters were in their infancy, and Zlotek was quick to react by modifying automotive sprag clutch designs for improved functionality in a helicopter drivetrain.

He registered his first patent in June, 1959, for a sprag retainer in a "one-way clutch" that ensured all sprags would simultaneously and equally roll to carry the load torque. In 1994, he registered his 19th patent, at the age of 75, for a sprag retainer with rotational restraint.

"I can't imagine that we would be the aerospace company we are today without Ted pursuing it and working so closely with our aerospace customers," says John Dunstone, Strategic Market Manager-Aerospace & Defense for Altra Industrial Motion, parent company of Formsprag Clutch.

"This business is very much based on long-term relationships. It was Ted who sowed the seeds and nurtured the relationships and built such a strong culture of customer satisfaction. I've never met anyone who is so customer focused."

Here's a classic reaction to Ted Zlotek, related by Jack Pederson, Formsprag Business Manager, Aerospace & Defense:

"We had a group from the U.S. Army here last fall for a quality audit and one of the guys just stopped short and exclaimed, "Ted Zlotek! I'm so pleased to meet you!" I think we could have passed the audit right then and there. This guy had worked on the V-22 more than a decade ago and was familiar with the clutch design, but he hadn't actually met Ted. In the world of overrunning clutch design, Ted is world renowned."

Dunstone can count dozens in the helicopter industry who Ted has taught and mentored, including himself:

"He remembers all the unbelievable number of applications he's worked on, what the design considerations were, and the names of everyone involved… I've only known Ted for 20 of the 90 years of his life - he was 70 when I met him as a college co-op student. And to be honest, I was intimidated, because he had been around forever. But every single time I had a question, he more than made time for me – just a college kid with, looking back now, what was probably a pretty silly question."